IBC Onshore Pipeline Engineering
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Pipeline Failures and Integrity Management

Alan Denney

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- Pipeline failures and their causes
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  - Visual surveys
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  - Internal corrosion
  - Intelligent pigging
- Pipeline integrity management
  - Regulations and codes
  - Developing the system
  - Data management
  - Risk based inspection
- Repair and rehabilitation

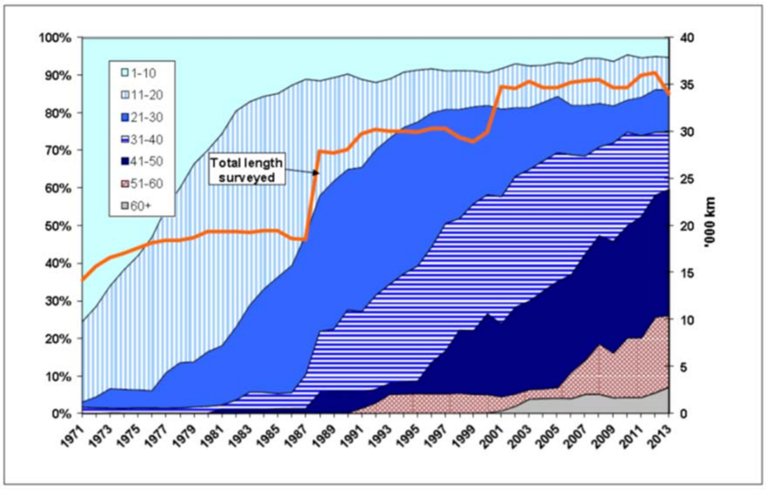
Pipeline failures and their causes

Bodies compiling failure statistics

Pipelines are very safe – 100x safer than highway tank trucks (Kiefner USA)

- European Oil and Product Pipelines
  - CONCAWE (Conservation of clean air and water in Europe).
  - Crude oil and petroleum products.
- European Gas Pipelines
  - EGIDG (European Gas Incident Data Group).
  - Every 3 years
- British Oil and Gas Pipelines
  - UKOPA (UK Onshore Pipeline Operators' Association).
  - Published annually.
- USA – Office of Pipeline Safety(OPS)
  - Part of U. S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration.
  - Published annually

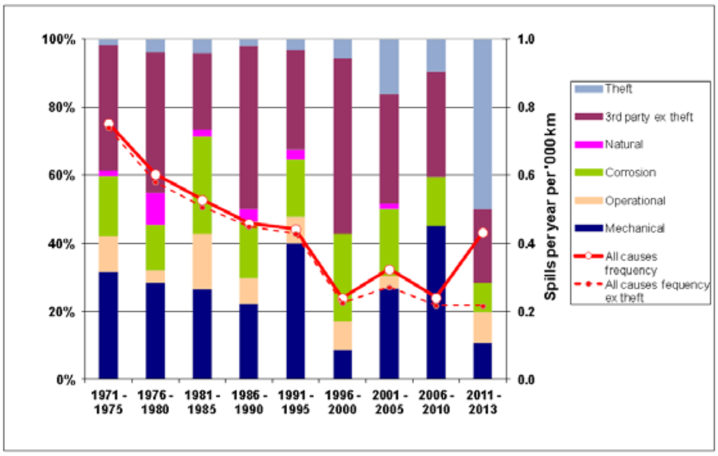
Pipeline age distribution – liquid lines Europe



To 1988 oil industry only. 1988 NATO added. 1991 East Germany added. 2001 and 2003 Czech and Slovak lines added

Data for liquid transmission pipelines in Europe to 2013. Source Concawe

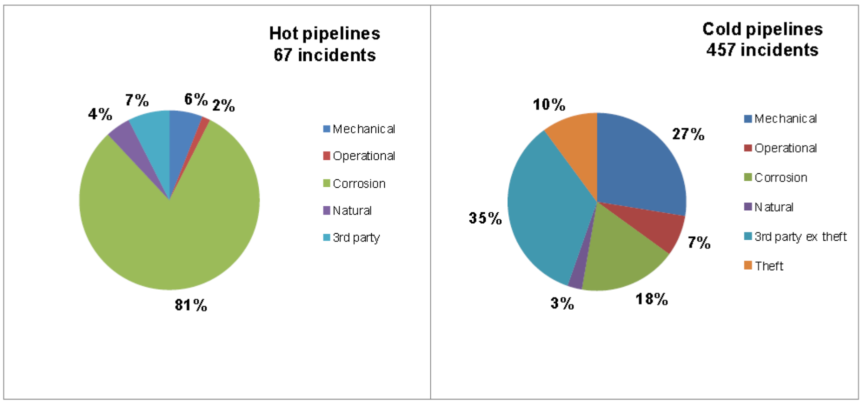
Causes of spillage - cold lines



Data for liquid transmission pipelines in Europe to 2013. Source Concawe

Failure rate has not increased with age for lines up to 45 years old (Concawe)

Comparison between hot and cold lines



Data for liquid transmission pipelines in Europe 1971 to 2013.

Source Concawe

Third party damage and its avoidance

- Third party interference is the main cause of failures
  - 4 x that of construction or materials defects
  - 4 times that of corrosion
  - In 2007 avoidable 3rd party activities accounted for 34.6% of serious incidents, 36% of fatalities and $4.9m of property damage (source OPS: USA)
- Management of the pipeline right-of-way is a vital part of pipeline integrity management
  - Detection of 3rd party activities
  - Supervision of any work on or adjacent to the line
  - Carried out by land based, and/or aerial surveillance
    - *Identification of deterioration; erosion, subsidence*
    - *Detection of small leaks, not otherwise detected*
  - Education of Landowners

Some notable pipeline failures

Failure due to corrosion of old 'uninspectable' line

- Carlsbad New Mexico 19th August 2000
- Natural gas explosion at a campsite
- Pipeline was 50 yrs old
- Crater 86ft x 46 ft x 20ft deep

- 12 members of one family died
- Pipeline was not inspectable by 'intelligent pigs' due to 'dips and turns'
- $2.5m fine on Operator
- $14m paid in initial lawsuits.

Failure due to accelerated internal corrosion

- 21st March 2006
- Leak from Trans-Alaska pipeline
- At least 190000 litres of oil released onto tundra
- Corrosion at a point where line dips for Caribou to cross,
- corrosion rate had unexpectedly accelerated

- Prudhoe Bay oilfield closed down on 9th August 2006 losing 400000 barrels of oil/day production
- US$12 million federal criminal fine,
- US$4 million in criminal restitution to the state
- US$4 million for Arctic research.
- BP Exploration (Alaska) Inc. on probation for three years.

Failure due to external stress corrosion cracking

- 29th July 1995
- Failure on a 42 inch grade X60 natural gas pipeline approx 3 km southeast of Rapid City Manitoba. (Pup was X65)
- 19.6 m^3 gas consumed by fire
- The initial rupture occurred as a result of a pre-existing stress corrosion crack (SCC).
- This piece of pipe had been fabricated in the field and coated with polyethylene tape.

Failure due to inadequate monitoring of adjacent works

- Bellingham Washington State USA
  - 10th June 1999 pipeline ruptured
- Leaked 237000 gallons of gasoline into Hannah and Whatcom Creeks
- Vapour cloud ignited at Whatcom Creek

- Two 10 year old boys and an 18 year old died
- $45m losses
- NTSB stated
  - damaged during construction of the water plant in 1994 – 5 years previously
  - inadequate supervision of this work
  - Pipeline operator has misinterpreted in-line inspection data and failed to repair
  - inadequacies in the safety devices

- Initial fine of 3.05m on Operator
- $7.8m fine on companies involved
- Four employees indicted for violations of pipeline safety act

Failure due to accidental third party damage

- Ghislenghien, near Ath, Belgium 30th July 2004
- Natural gas pipeline from Zeebrugge to France
- Major gas leak detected and emergency services called. ‘when emergency services arrived there was an explosion’.
- Service station blown up, factory destroyed. Cars blown 500m, total destruction zone of 400m radius. Debris found 6km away.
- Factors:
  - Construction work had progressed around the pipeline
  - A new roadway had been constructed over the line
  - A 10mm deep notch on the pipe surface initiated the failure
  - There was also the possibility of damage being from earlier agricultural machinery

Ghislenghien,Belgium 30th July 2004

Photos courtesy of BBC website

Deaths: 23   Injured: 122 – about 25 critically

San Bruno natural gas transmission line failure

- San Bruno California
- 9th September 2010
- 30 inch gas transmission pipeline rupture
- Pipeline was 60 years old

The damage

- 38 homes destroyed
- 8 persons killed, many more injured
- Blame initially placed on defective welds
- 8.5 m length of pipe was sent 30 m.
- The blast created a crater 51 m long and 7.9 m wide

Investigation revealed

- the line pressure had been increased
- Residents reported smelling natural gas in the area in days prior to failure.

An independent audit from the State of California dated January 13, 2012, issued a report stating that PG&E had diverted over $100 million from a fund used for safety operations. Source: Wikipedia.

Risks to an operator

Risks

- Loss of production
- Cost of remedial work
- Cost of incident management
- Legal action
- Damage to reputation and public image
- Increasing external regulation which may be excessive or inappropriate

What the Operator needs to avoid the risks

- Asset availability to assure revenue and a financial return
- Compliance with regulatory requirements
- Assured system integrity
  - *Pipeline integrity and operability*
  - *Public and personnel protection*
  - *Protection of the environment*

Methods of pipeline monitoring

- **Routine visual surveys**
- **External corrosion monitoring**
  - Cathodic protection potential
  - Operation of CP system
  - Coating integrity
- **System-based monitoring**
  - External interference
  - Leak detection
- **Monitoring for internal corrosion**
- **Intelligent pigging**

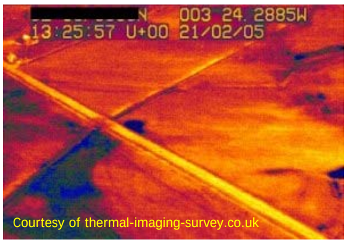
Pipeline inspection – visual inspection

Regular aerial surveys

- Using helicopters or fixed wing aircraft
- Detection of leaks
- Inspect for naturally occurring damage
- Identify ROW encroachment and third party damage
- Now use GPS referencing and reporting
- Integrated with video and digital mapping
- Thermal imaging

Foot patrols

- Probably a two-yearly cycle



Colourised thermal image showing a leak (blue/green) from a trunk main water pipe.

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Basic data for external corrosion monitoring

Objective

- *To monitor actively external corrosion potential and minimise failure risk*

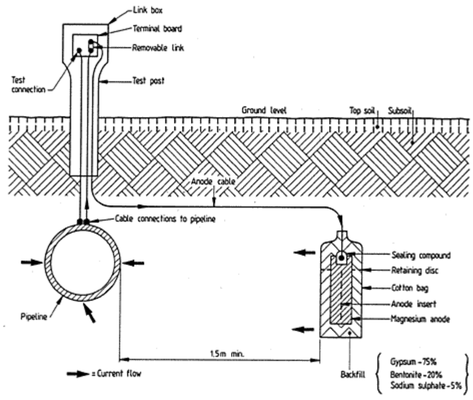
- Input data required
  - *Route mapping information: elevation profile*
  - *Crossings (rail, road, other pipelines)*
  - *CP installation locations*
  - *Resistivity profile along the line*
  - *Failure, repair, replacement and modification history*
  - *Historical data on CP potential distribution*
  - *Historical data on coating condition*
  - *Sites of possible electrical interference (DC rail, AC lines)*

Surveys undertaken

- CP protection potentials
  - *Test post measurements*
  - *Over the line potential measurements*
- Coating surveys
  - Pearson survey
  - Direct current voltage gradient
- Stray current corrosion monitoring
- AC corrosion monitoring

Potential measurement - test posts

CP test posts would be located at:



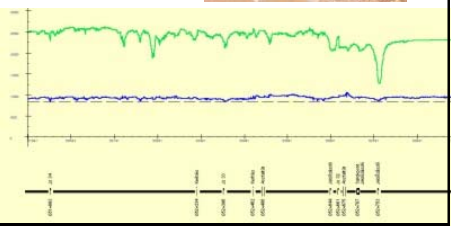
Source: Adam Junid

- Either side of major roads, rivers, railway crossings
- At metallic foreign service crossings
- At isolating joints
- Where metallic casings have been used (cables to both the pipeline and the casing)
- Two-wire current measurement spans

Potential survey - CIPS

A close interval potential survey is the measurement of the local potential at all points along the pipeline. It is carried out when the T-R units have been given their initial settings and the pipeline has polarised.

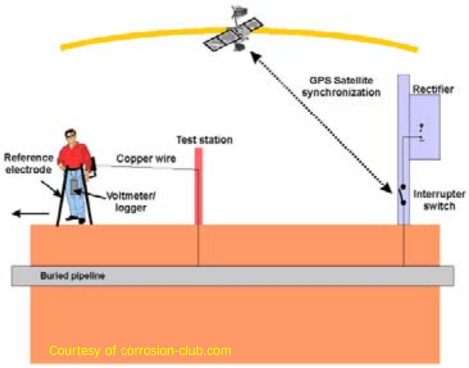
CIPS in Oman



Principle of close interval potential survey (CIPS)

Aim: to measure the pipeline protection potential at all points of the pipeline

- Operator is connected to pipeline via a trailing insulated Cu wire connected to a test post
- Potential measurements taken at 1m intervals
- True pipe- to-soil potential requires eliminating the error associated with voltage (IR) losses through the soil
- CP current flow is interrupted and an instantaneous 'instant-off' potential is measured.



- Switching is fractions of a second to a second, off cycles are short to prevent depolarisation
- All sources have to be synchronised.
- Requires logistical support and collaboration between Operator and survey contractor

Coating survey – DCGV

DCVG survey

Current interrupter in circuit in T-R unit

- A switched DC signal is impressed on the pipeline.
- The sticks each have a half cell in contact with the ground.
- the surveyor walks the pipeline route above the pipeline and reads the voltage gradient between the half cells on the milli-volt meter.
- As a fault is approached, the surveyor will see the milli-volt meter respond. As the fault is passed, the needle deflection reverses.
- The position of the probes is found where the needle shows no deflection. The fault is then sited midway between the two half cells.
- This procedure is repeated at right angles to get directly above the coating defect.
- Once located measurements are made to assess the severity of the defect.

CP system inspection and routine monitoring

- Routine inspection of the equipment and monitoring of the CP levels is required
- Critical items, should be monitored monthly;
  - *power sources,*
  - *cross bonds*
  - *areas of severe interaction,*
- Less critical items can be monitored less frequently, e.g. annually
- Table 4 of ISO 15589-1 gives an outline for the above
  - *ISO 15589-1: Cathodic protection of pipeline transportation systems -- Part 1: On-land pipelines*
- The CIPS survey should be repeated at intervals of a few years
- Data sent in from the SCADA system should be routinely confirmed by site testing
  - SCADA *supervisory control and data acquisition*

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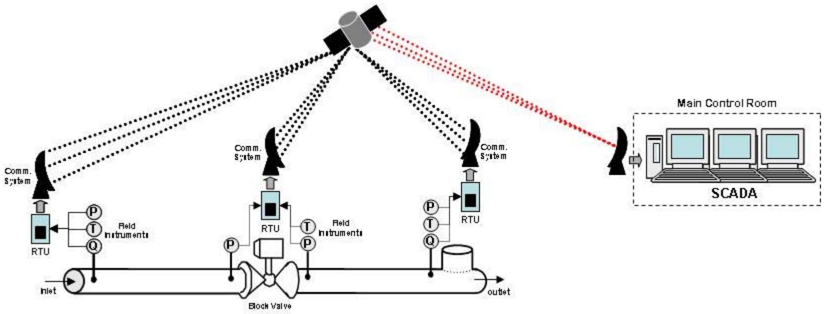
Leak detection

Monitoring of operational and hydraulic conditions

- Volume balance comparison
  - *Identification of imbalance in and out, measured over specified time period*
- Rate of pressure or flow change
  - *Rapid depressurisation, rapid changes in inflow or outflow, and differences*
- Real time transient monitoring
  - *Mathematical model is comparing measured pressure and flow data*
- Statistical methods
  - *Comparison of live data with statistical norms*

System-based monitoring

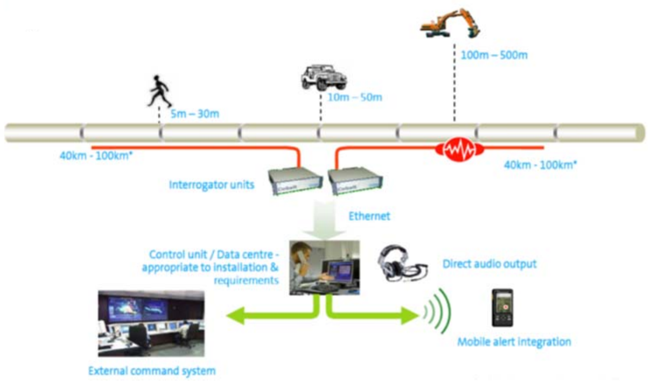
Leakage monitoring and pipeline pressure, flow input/output comparison, can be monitoring in real time using advanced software applications on top of SCADA



Pipeline leak detection – external sensors

- External cables or sensors for detecting leaks/spills
  - Liquid sensing cables
  - Fibre optic cables
  - Acoustic emission detection
- Work by sensing temperature changes
  - Gas leaks give a large change (J-T cooling)
  - Oil leak systems have to be more sensitive
- Measurements taken every 1m along the cable length
- interfaces with client SCADA every 90 km
- Can be integrated with structural movement sensors –earthquakes, intrusions on the line
- Can be integrated with telecoms

Acoustic surveillance – Optasense ™

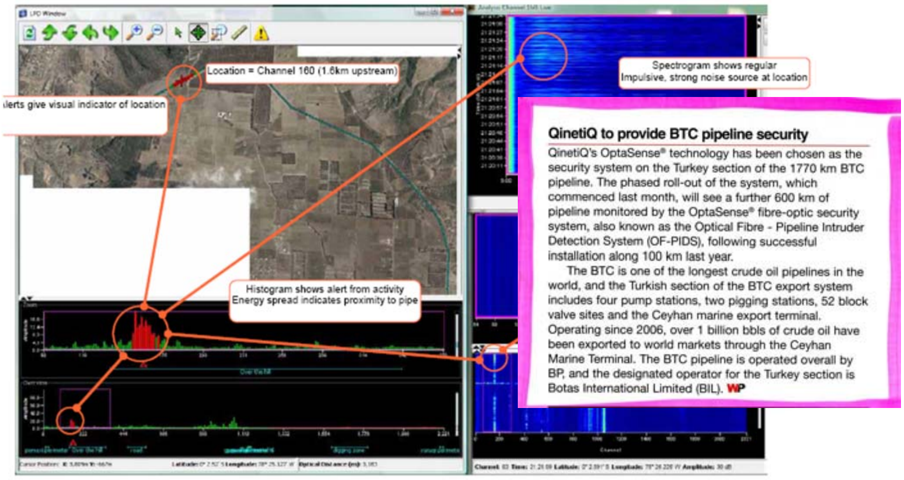


- Signal processing is used to detect and locate acoustic events over length of line
- Can use existing optical communications fibres
- Monitoring in 40km lengths to a resolution of 10m

Detects

- Human interference
- Groundworks and digging
- Leaks
- Tracks intelligent pigs
- Perimeter surveillance

Data presentation



QinetiQ to provide BTC pipeline security

QinetiQ's OptaSense® technology has been chosen as the security system on the Turkey section of the 1770 km BTC pipeline. The phased roll-out of the system, which commenced last month, will see a further 600 km of pipeline monitored by the OptaSense® fibre-optic security system, also known as the Optical Fibre - Pipeline Intruder Detection System (OF-PIDS), following successful installation along 100 km last year.

The BTC is one of the longest crude oil pipelines in the world, and the Turkish section of the BTC export system includes four pump stations, two pigging stations, 52 block valve sites and the Ceyhan marine export terminal. Operating since 2006, over 1 billion bbls of crude oil have been exported to world markets through the Ceyhan Marine Terminal. The BTC pipeline is operated overall by BP, and the designated operator for the Turkey section is Botas International Limited (BIL). WP

Figure 5: Example of manual digging activity on a pipeline deployment showing the graphical alerts as well as the more detailed analysis information revealing the nature of the threat. The digging was not a simulation but an actual threat event noted during deployment.

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Internal corrosion - conditioning and monitoring

COMMON PROCESS CONDITIONING OPTIONS

- Dehydration (drying)
- Chemical Treatment (Inhibitors, pH control)
- Gas removal (sweetening)

Successful and efficient corrosion management requires process monitoring and corrosion monitoring. Examples:-

- Inhibitor injection rate
- Inhibitor residuals
- Dew point
- Water chemistry and electrical conductivity
- Operating window (temperature pressure and flow)
- Chemical analysis - liquids and gases
- Scale analysis.

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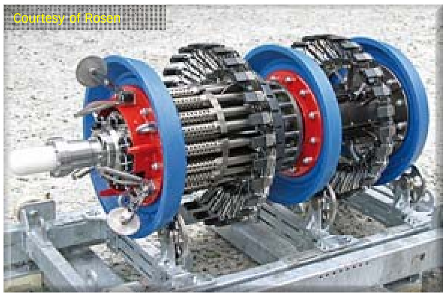
Caliper pig

- A geometry / caliper pig is designed to record conditions, such as dents, wrinkles, ovality, bend radius and angle

- Spring loaded sensor arms coupled to sensors
- Odometer (distance measurement)
- Data collection module
- Database of results and software for visualisation



- Contact sensor arms – all obstructions
- Non-contact electronic sensor – pipewall only
- Electronic odometer
- XYZ mapping – bend radii, length and direction
- Database of results and software for visualisation

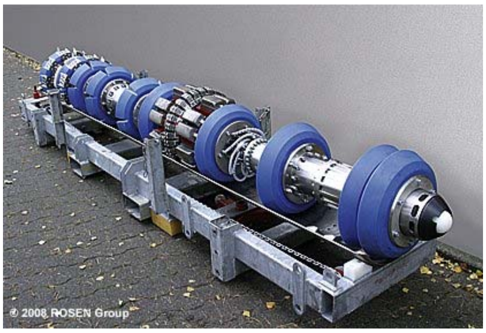
Intelligent pig runs

Intelligent pigs are used to determine wall thickness loss - internally and externally.

Data is presented as metal loss around the circumference correlated against distance.

Main type - magnetic flux leakage

- A magnetic field is induced locally
- The disturbance to the magnetic field is sensed.
- The processed data is presented as percentage wall loss per channel, against location.

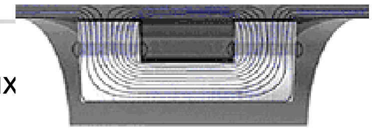


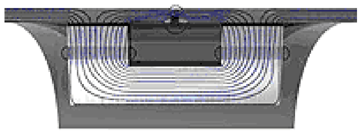
MFL pigs can detect:

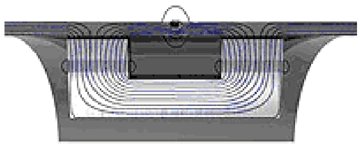
- Fittings
- anodes and CP points
- Close metal objects and magnets
- *Volumetric metal loss*
- Hard spots
- Girth weld anomalies

Types of intelligent pigs - MFL

Method: high resolution magnetic flux leakage intelligent pigs


Flux line distribution of pipe without flaw


Flux line distribution of pipe with internal flaw

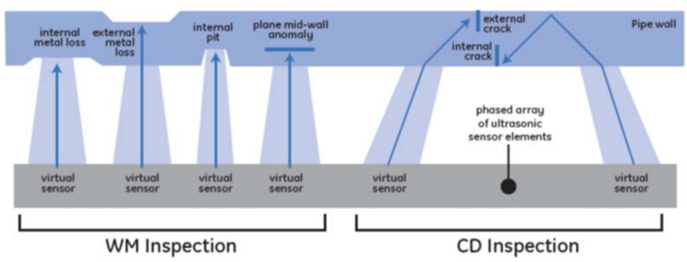

Flux line distribution of pipe with external flaw

- *The pipe wall is magnetized axially to saturation level using permanent magnets. High magnetization levels are necessary.*
- *In a pipeline with no flaws, the magnetic flux travels undisturbed through the walls.*
- *In the presence of internal and external metal loss, the flux "leaks" out of the pipeline and is recorded by hall effect sensors,*
- *The sensor system and electronics give 360-degree full circumferential coverage.*

Ultrasonic intelligent pigs

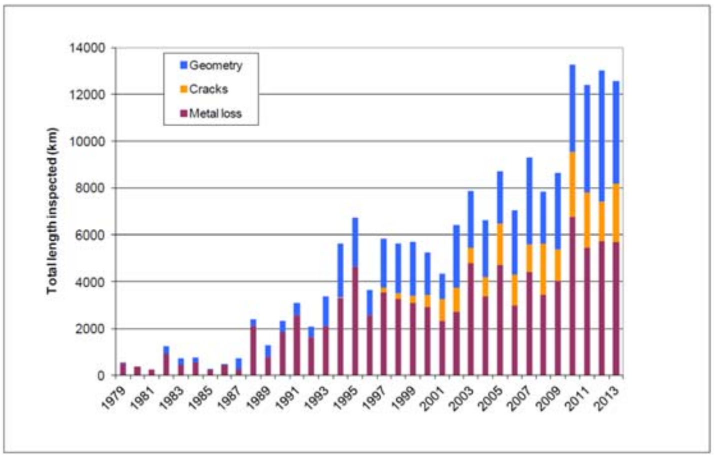
- GE Ultrascan
- Uses phased array ultrasonics

Courtesy GE/PII



- Capable of detecting and sizing a wide variety of defect types, including longitudinal and transverse cracks (min. 25mm x 1mm with 90% POD)

Trend in the use of intelligent pigs



Annual inspections by type of intelligent pig
Data for oil transmission pipelines in Europe to 2013. Source Concawe

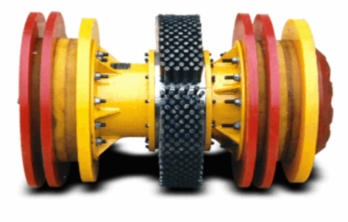
Preparatory work (National Grid gaslines)

It is necessary to do preparatory work on the line before running the intelligent pig.

- Proving pig
  - Can pass bore reductions of up to 30% pipe diameter
- Geometry (Caliper) pig
  - Measure size and location of bore reductions
- Bend profile pig
  - Not necessary if records show bends are 3D or greater
- 4 cup swabbing pig (if required)
- Magnetic brush cleaning pig
- *High resolution MFL inspection pig*

Cleaning pigs

- Often specially designed for the specific operation
- May be fitted with brushes, scraper blades, magnets, wax removal disks



Brush pig

waxing pig

Courtesy Pigs unlimited

Blade pig

Courtesy Rosen Engineering

Defect assessment

See the next presentation

Pipeline Integrity Management System

- Definitions
- Regulations and codes
  - *National and international*
- Developing the PIMS
  - *Direct Assessment*
  - *Data required*
  - *PIMS structure and organisation*
- Data management
- Risk based inspection

Definitions

- Integrity – "….. being complete….."
- Pipeline Integrity Management - the steps taken to ensure the pipeline is, and will remain, complete and operational.
- It includes:
  - ensuring the pipeline operates as required
  - avoiding leaking or failure of the pipeline
- Pipeline Integrity Management is an auditable means of demonstrating that the pipeline is 'Fit for purpose'
- Pipeline Integrity Management System
  - "a system to ensure that pipeline network is safe, reliable, sustainable and optimised".

Regulations - EU and UK

- EU – European Pipeline Safety Instrument (proposed)
- UK Pipeline Safety Regulations 1996
  - Pipelines transporting gas above 7 barg are classified as Major Accident Hazard Pipelines (MAHPs)
  - Notification requirements for MAHPs.
  - Preparation of Major Accident Prevention Document (MAPD), emergency procedures and information to local authorities for inclusion in Emergency Response Plan
- EU - The Pressure Equipment Directive (97/23/EC, PED) and the UK - Pressure Systems Safety Regulations 2000 (PSSR)
  - Applies to pipework with MAOP exceeding 2 barg
  - AGIs – not the pipeline
- Energy Institute document 'Guidance for corrosion management in oil and gas production and processing'.
  - Focus is on management of pipeline hazards of operating systems
  - http://publishing.energyinst.org

Regulations - USA

Federal regulations for pipelines require operators:- *"to enhance and validate pipeline integrity, to provide improved protection for High Consequence Areas (HCAs) that could be affected by an unintended release of hazardous liquids from a pipeline".*

- Reference: Title 49 of the Code of Federal Regulations (CFR), Parts 190-199. Clause192-903

HCAs are defined in terms of the potential impact radius within which the potential failure of a pipeline could have significant impact on people or property. The definition is in terms of pipeline location classes and includes:

- Density of buildings designed for human occupancy
- Sites used for recreational purposes
- Sites used for persons who are impaired (hospitals etc)

The Code does not state the means.

Individual states have specific pipeline safety regulations.

Codes and Direct Assessment - USA

- *ANSI/ASME B31.8S-2014: Managing System Integrity of Gas Pipelines*
- *API 1160: 2013. Managing System Integrity for Hazardous Liquid Pipelines*
- *NACE SP0502-2010: Standard Practice - Pipeline External Corrosion Direct Assessment Methodology*

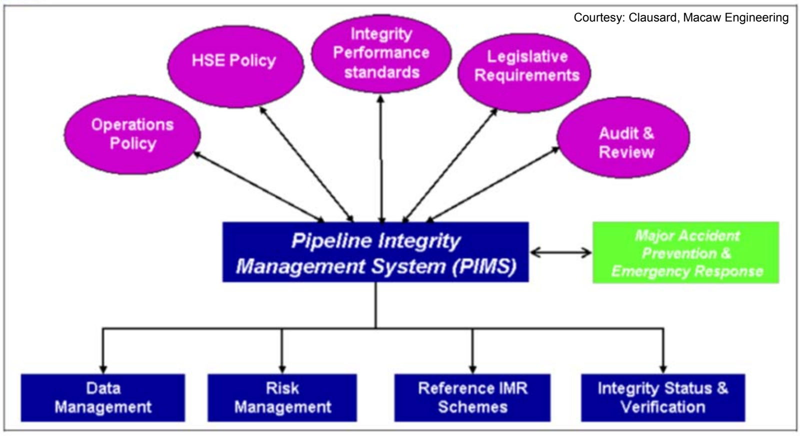
Direct Assessment is used in USA to demonstrate the integrity of pipelines which could not be inspected using 'intelligent pigs'.

- Involves the collection, analysis, assessment and integration of data
  - *Direct and indirect examination methods, including above ground survey data*
- The methodology defines:
  - *locations to be physically examined*
  - *the means of examination*

Pipeline Integrity Management System (PIMS)

- PIMS is the development of an inspection and management programme under a set of objectives, policies and practices.
  1) Setting the policy and strategy
  2) Methodology
     - *Consequence based*
     - *Threat based*
     - *Risk based*
  3) Data
     - *Data to be collected*
     - *Modelling to be used to meet the methodology*
  4) Systems and tools
     - *Software for data collection and storage*
     - *Modelling software (for consequence and risk-based analysis)*
  5) Definition of inspection plans and procedures
  6) Implementation
- Review and revise the system based on experience

Example of operator's PIMS structure



An emergency response plan is required under Government legislation in the UK

API 1160 approach

API 1160 "Managing system integrity for hazardous liquid pipelines" provides a strategy for development of a PIMS.

- Establish HCAs
- Develop Baseline Assessment Plan detailing inspection methods to be used for assessing pipeline integrity
- Undertake Baseline Integrity Assessment utilising a risk-based process to:-
  - conduct the inspections
  - integrate other relevant data
  - derive location, nature and relative risk of features which could affect integrity.

Example core data necessary within a PIMS

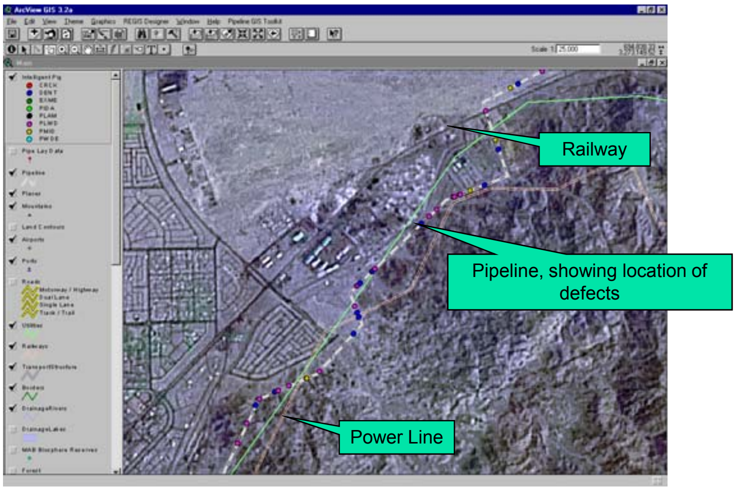
- Design parameters
  - Process parameters
  - Materials, coatings
- Routing information
- Desired operating parameters
  - Pressure and operating conditions
- Internal corrosion management data
- External corrosion management data
- Operational data
  - Safety systems – history of shutdowns
  - Failure history
  - Modifications made and the reasons

Management of data

- Effective management and integration of data is key to a functioning PIMS
- The elements include
  - the pipeline configuration data
  - The inspection and maintenance records
  - The pipeline information data
  - The RBI data

Geographical Information Systems (GIS)

Geographic Information Systems (GIS) can assist in visualisation of data.

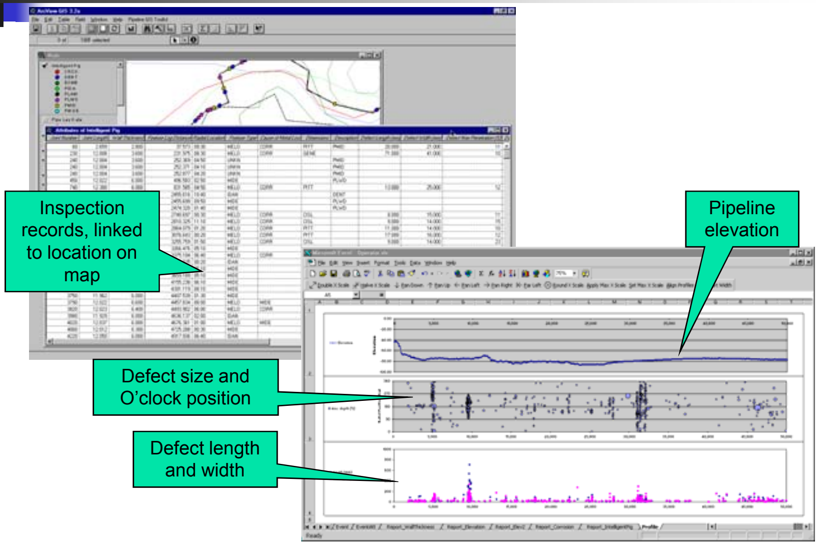


Geographic Information Systems

GIS present a tool for ready visualisation of pipeline data:

- Pipeline route
  - Maps
  - satellite images
  - aerial survey data
- Overlays to provide specific information
  - Identification of HCAs
  - Location of pumps, valves, off-takes etc.
  - Location of crossings
  - Local terrain and soil conditions
  - Defect locations
- Links to specific databases
  - Inspection planning database
  - Inspection reports

Data linking with GIS



Risk based inspection

- Risk is a function of the combination of
  - probability of an event
  - the consequence of the event
- For low risk we control: the probability of failure *or* the consequences

A large portion of risk is concentrated on relatively few items or areas. RBI assigns , for the assessed risk:

- *Appropriate types of inspection.*
- *Appropriate levels of inspection and monitoring*

Development of a risk-based inspection programme

- Analysis to establish the major threats to the pipeline
- Preliminary risk analysis
  - *Probability estimation*
    - Defect data
    - Defect frequency
    - Failure modelling
  - *Consequence estimation*
  - *Detailed investigations to confirm risk estimates for critical sites*
- Finalise risk assessment methodology
- Define appropriate inspection methods
  - *Failure modes and Effect Assessment*
- Development of the RBI plan and database
- Implementation of RBI
  - The outcome of inspection – to plan and organise remedial activities
- Re-assessment of risks and updating the database accordingly

Guidance on risk based inspection

- API Recommended Practice 580, Risk-Based Inspection, 3rd Edition February 2016
  - *gives recommended practice for risk-based inspection (RBI)*
- API Publication 581 - Risk-Based Inspection Technology. 3rd edition, April 2016.
  - *Covers procedures and methodology.*

The difference between API 580 and API 581
API RP 580 identifies the basic elements for developing, implementing, and maintaining an RBI program.
API RP 581 documents a quantitative approach to implementing RBI giving an assessment method for determining the Probability of Failure (PoF) and the Consequence of Failure (CoF) associated with each item of the system.

- Software based around API RP 580
  - Credosoft
  - RiskWise
  - Many others -

Repair and rehabilitation

Pipeline rehabilitation

Rehabilitation is often more economical than replacement.

Pipeline repair

- GRE wrap methods
- (e.g. Clock Spring or WrapMaster)
- Steel sleeves welded to pipeline
- Epoxy bonded steel sleeves (e.g. Petrosleeve ®)
- Weld repairs
- Pipeline bypass

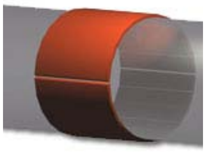
Coating repair

- Heat shrink sleeves
- Liquid systems
- Tape wraps

Welded sleeves and attachments

Examples

- Half shells
- Full encirclement sleeves
- Hot tap connections



Courtesy: Furmanite

Avoidance of problems

- Risk of burn-through
- Risk of hydrogen cracking
- Cooling effect of the process fluid

When and how should PIMS be implemented

- Progressively develop the PIMS from now
- Can commence PIMS by carrying out a Simple Pipeline Risk Audit (SPRA)
  - *Verify design and operating parameters*
  - *Route review against design assumptions*
  - *Development of list of non-compliances*
  - *Identify high risk areas*
- The steps required to implement from there depend on the status of the pipeline and the regulatory regime in which it operates.
- With a new pipeline: start to develop the PIMS during the construction phase, with setting the strategy and initiating data collation and inputting
- As the pipeline system ages the role of the PIMS in ensuring cost-effective risk management becomes increasingly vital.
  - *Progressive reduction in pipeline incidents on ageing pipelines is a result of PIMS.*

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- Furmanite
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It is possible that material from other organisations may have been used without acknowledging the original source. This can be corrected if the presenter is informed.

The end